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Does Harvest in West Slope Douglas-fir Increase Peak Flow in Small Forest Streams?

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ABSTRACT

Logging in the Douglas-fir forest has only minor effect on major peak streamflows which occur when soils are thoroughly wet. Exceptions are the early fall storms following the dry summers characteristic of the west coast climate. At this time, peak streamflow from unlogged areas may be less than in the harvested area because the soil in the unlogged area is drier and has greater moisture storage capacity than in the harvested area. These early fall storms rarely result in major peak streamflows.

KEYWORDS: Logging, stream gaging, Douglas-fir.

CONTENTS

The highly productive Douglas-fir region of Oregon and Washington lies to the west of the crest of the Cascades. Precipitation in this region ranges from about 35 inches to well over 100 inches annually, most of which comes during the winter months. Rainfall during the wet season fills the soil reservoir with the water needed to meet the demands of dense stands of rapidly growing trees. It is not unusual for precipitation to exceed the storage capacity of this soil reservoir which leads in turn to flooding of streams and rivers. Flooding may be serious locally or in rare cases may cause extreme damage over large areas. During or after each of these floods, accusations are freely voiced that the peak streamflow from the storm and resulting damage to downstream structures were made worse by logging in the Douglas-fir forests. But is this really true? Evidence is generally meager, but some field-scale studies are increasing our knowledge of forest-flood relations.

In a detailed analysis of an experiment at the Coweeta Hydrologic Laboratory in North Carolina, Hewlett and Helvey (1970) show the effect of clear felling (with felled trees left in place) on the production of floodwaters. The noncommercial nature of the Coweeta experiment allowed these authors to make a clear distinction between the effects of clear-cutting alone and the additional effects of roads and logging on stormflow volumes and peaks. Although the main peak flows increased slightly, the evidence that clear felling resulted in an increase in record peak flows was not conclusive. The authors, however, point out that there was a significant increase in total volume throughout the stormflow period and speculate that such increases could, under some circumstances, contribute significantly to downstream flooding.

In the Pacific Northwest, Gilleran,[1/] Harper,[2/] and Hsieh,[3/] analyzing data from the Alsea watersheds in the Douglas-fir forests of the Oregon Coast Ranges, found significant changes in some factors controlling maximum streamflow from small- to moderate-sized storms. In general, they found that roads which altered 3 to 4 percent of the drainage area had little influence on peak streamflow. When over 12 percent of the drainage area was in roads, there was a significant increase in peak flows which was further increased when 75 percent of the land surface in the drainage was logged. Clear-cut drainages also showed marked increases in peak flows--some as much as one-third in the winter months. Largest changes in peak streamflow were on the smallest subwatersheds. The main drainage showed less change in peak flows.

These two studies present statistically sound conclusions of the average change over a wide range of peak flows from several years of record. However, when we are concerned with damages from high streamflow, we must look most closely, not at the average condition, but at the largest streamflow events which occur only infrequently. Such streamflow periods are sufficiently rare within the span of time between logging and reestablishment of the forest that they must be examined individually and, therefore, are

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1/ Dennis James Gilleran. Rapid calibration of coastal streams to detect effects of road building. M.S. thesis on file at Oreg. State Univ., Corvallis, 51 p., 1968.

2/ Warren Charles Harper. Changes in storm hydrograph due to clearcut logging. M.S. thesis on file at Oreg. State Univ., Corvallis, 116 p., 1969.

3/ Frederick Shukong Hsieh. Storm runoff response from road building and logging on small watersheds in the Oregon Coast Range. M.S. thesis on file at Oreg. State Univ., Corvallis, 149 p., 1970.

not readily subject to statistical analysis. In their study, Hewlett and Helvey (1970) found that of two record high peak flows, one was higher after clearcutting than would be expected; the other lower. Our study shows considerable evidence that clearcutting does not necessarily increase major peak flows.

In discussing the effect of logging on peak flows, I find it necessary to make some assumptions. My first assumption is that logging--including clearcutting--has no significant influence on either total precipitation or on the intensity with which it falls. This has been fairly well accepted over the years.

The second assumption is that the hydrologic properties of forest soils are not greatly changed by timber harvest. Logging activities may alter soil characteristics to some extent; but we are reasonably sure that in the Pacific Northwest, infiltration rates on most of a logged area are rarely reduced below precipitation rates.

In western Oregon, Dyrness (1969) reported rapid percolation rates for surface horizons due to the porous and highly aggregated nature of the soil. Surface runoff (overland flow), seldom, if ever, occurs over extensive areas of forest land. Dyrness (1965, 1967) estimated that about 4 to 20 percent of a cable-yarded clearcut was deeply disturbed or compacted to some extent. In tractor-logged areas, over one-third of the area may be compacted or deeply disturbed. With the exception of the tractor skidroads, these areas are generally discontinuous, and do not necessarily have surface infiltration rates sufficiently reduced to cause other than local surface runoff. Truck and skidroads, landings, gravel pits, and other severely disturbed areas are exceptions; but surface runoff that does occur usually flows to other areas where the infiltration capacity is sufficient to handle it.

Slash burning may alter soil properties where the intensity of the burn is high; but in most slash burns, severely burned areas represent only a small portion of the total area. Tarrant (1956) found that although severe slash burning lowered the rate of water movement into some soils, the area severely burned was so small that the overall effect on soil moisture properties and water flow was minor.

Conditions favorable for infiltration are maintained where continuous forest production is practiced such that soon after logging a new cover of vegetation appears which in a short time is dominated by forest trees. Clearcutting the forests to convert to another cover or use or measures to prevent revegetation do not fit the above conditions. In the great majority of cases, both private and government forests are managed for continuous forest production.

Under these conditions, in which the major portion of the forest soil remains hydrologically active, peak streamflow should be a function primarily of precipitation characteristics, stream channel geometry, and antecedent moisture conditions. If this is the case, forest cover should play a relatively minor role in determining the peak rate of streamflow during our major storms when rainfall is high and soils are near saturation during the midwinter rainy season. Other criteria of storm runoff characteristics such as mean peak flow, time to rise, total volume of stormflow, and frequency of stormflows of a given size have been used to demonstrate that forest cutting changes the storm hydrograph. However, when flood damage to drainage structures or other improvements are considered, the maximum peak is most important. In this study, therefore, we have considered only the effect of logging on maximum instantaneous flows from major storms.

THE STUDY AND ANALYSIS

The data on which this report is based came from experimental watersheds on the U.S. Forest Service's H. J. Andrews Experimental Forest, an area typical of much of the west slopes of the central Cascade Range. The results should be generally applicable to forested areas in the Pacific Northwest west of the Cascade crest and other areas where the soils are relatively deep and porous and where precipitation associated with major storms occurs primarily from warm, moist, stable airmasses which produce large quantities of precipitation at low intensities. The results would not necessarily apply to areas where precipitation is frequently of high intensity nor to those drainages that have a maximum peak from snowmelt in the spring. The latter is highly variable depending on accumulated snow and season of melt.

Characteristics of the watersheds on the H. J. Andrews Experimental Forest are described in an earlier publication (Rothacher et al. 1967). Briefly, these watersheds are 150 to 250 acres in size and originally supported a dense stand of old-growth Douglas-fir on steep, northwest-facing topography. They receive over 90 inches of precipitation annually. Most of the precipitation comes as rain during the months of October through April. Intensity is generally light; but long-duration, steady rains may total 5 to 6 inches or more in a day and over 30 inches a month. Most of the watersheds' area is below 3,000 feet, and temperatures are mild. Usually a snowpack will form after the first of the year at elevations above 3,500 feet; but below this, snow typically comes and goes during the winter months depending on frontal weather activity. Although rain alone can produce excessively high streamflow, most major floods occur as a rain-on-snow event associated with an extremely wet soil mantle (fig. 1).

The major portion of our analysis is based on streamflow peaks greater than 10 cubic feet per second per square mile (c.s.m.) that were recorded from 1957 to 1969 on two experimental watersheds. The unlogged watershed is 150 acres in size; the clearcut watershed, 237 acres. During water years (October 1 - September 30) of 1957 through 1962, both watersheds were unlogged. The relationship between peak streamflow measured on the two watersheds during each storm serves as the standard against which postlogging peak flows are measured. During the 1963-64 years, logging on the clearcut watershed was in progress. Logging was by skyline crane and without roads, a yarding system which resulted in little soil disturbance. Data from this

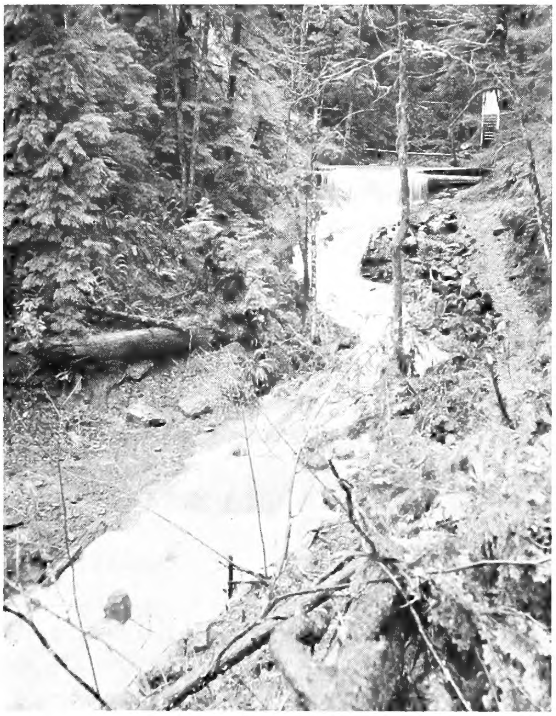

Figure 1.--*Peak streamflow from small experimental watershed at H. J. Andrews Experimental Forest.*

period of rapid change were omitted from the analysis. By the beginning of the 1965 water year, trees had been felled on over 80 percent of the drainage and logs had been yarded from 70 percent. Logging was completed during the summer of 1966, and the entire drainage was broadcast burned in October of 1966 (fig. 2). Reestablishment of vegetative cover was rapid after burning, although there has been almost no accumulation of litter, and bare soil has remained near 50 percent (table 1).

To obtain sufficient data on larger storms after logging, it was necessary to extend analysis over the 1965-69 water years even though logging was not completed until the summer of 1966. These years include a rather wide range of conditions changing from 20-percent old-growth

Figure 2.--*Clearcut and logged watershed on H. J. Andrews Experimental Forest the first year after burning.*

Table 1.--*Total understory vegetation cover and exposed mineral soil after clearcutting of timber and after burning of logging residue on clearcut watershed*

Year	Condition	Vegetation cover[1/]	Bare ground[2/]
		Percent	
1962	Undisturbed	86	4
1963	Being harvested	--	--
1964	Being harvested	--	--
1965	Being harvested	--	--
1966	After logging	54	12
1967	After burning	30	53
1968	Revegetating	76	54
1969	Revegetating	75	48

Source: Dyrness 1965, 1967, and unpublished data.

[1/] Sum of crown canopy coverage in the understory is the total of all layers. For comparison with postlogging measurements, the 1962 data do not include overstory tree cover.

[2/] Bare ground may occur under vegetative cover. Thus, vegetative cover plus bare ground can add to greater than 100 percent.

cover to completely logged and freshly burned, then to a partial cover of herbaceous and low shrubby vegetation cover. These conditions are, however, in sharp contrast to an old-growth forest. The transition is that which usually takes place during conversion from old-growth to second-growth Douglas-fir stands, i.e., the land does not remain devoid of vegetation for any appreciable length of time.

Peak flows for the 1965-69 water years were compared with predicted flows based on the 1957-62 calibration period using standard linear regression techniques. In an attempt to better explain the deviations of postlogging peak flows from the prelogged relation, a stepwise regression was performed on the posttreatment data to test the following series of factors related to precipitation patterns and indirectly to antecedent moisture conditions:

Precipitation:

1. Total for day of peak streamflow.
2. Maximum 6-hour intensity preceding peak.
3. 7-day total preceding peak.
4. 14-day total preceding peak.
5. 30-day total preceding peak.
6. Day number (representing time since fall rains began).

There are, of course, other factors that we know influence peak flows such as soil properties, snow cover, and channel geometry. For the study area, soil properties influencing streamflow did not change greatly. Snow and soil wetness are indirectly represented in the precipitation factors.

RESULTS

A highly significant linear regression, (.01 level, $r^2 = .95$), relating the two watersheds, was calculated for all peak streamflow periods for the years 1957-62 when both were unlogged. Although the individual points are omitted, the relationship is illustrated by the solid line in figure 3 (the line of best fit of the points), and the dashed 95-percent confidence lines on each side of the regression line. This is the standard against which changes are measured.

Also in figure 3, all peak flows during the postlogging period 1965-69 and exceeding 10 c.s.m. on the unlogged watershed were plotted over the comparable peaks on the logged watershed. The circled points are the first fall storms and will be discussed later. Many of the peak flows are well within the 95-percent band surrounding the prelogging regression line, suggesting that they do not deviate materially from the peak streamflows we would have predicted from prelogging relations. The great majority of the peaks that were greater than we would have predicted are from relatively small storms which produced peak flows less than the postlogging period mean of 29.9 c.s.m. on the unlogged watershed. Flow during a few of the larger storms also is appreciably higher than would have been expected if timber had not been harvested.

AVERAGE PEAK STREAMFLOW INCREASED

The regression for all storms over 10 c.s.m. during the postlogging periods is also shown in figure 3. This relationship was highly significant although the lower correlation coefficient ($r^2 = .75$) indicates greater postlogging variation. A covariance analysis, designed to test the difference between the two regressions,

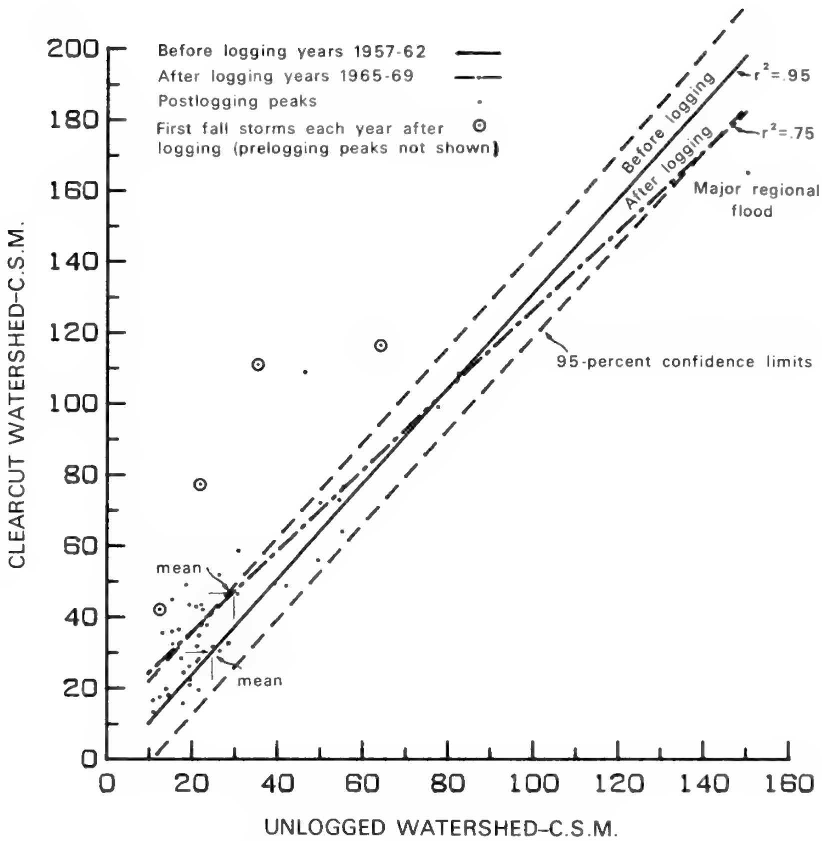

Figure 3.--*Peak streamflow relations of two experimental watersheds on the H. J. Andrews Experimental Forest before logging and after clearcutting. Before-logging data points not shown.*

shows that the slopes are significantly different (.05-level), indicating that logging has caused a general change in peak streamflow. The slopes of regressions, however, indicate that extremely high peak flows may be no greater after logging than would have been expected before logging. Unfortunately, data for major storms which occur during the period of minimum vegetation cover after logging are rare and the postlogging regression is strongly influenced by the single high point which represents the major regional storm of December 1964.

Hydrologists have traditionally used regression analyses to predict response of one watershed that is to be treated from another control watershed. At the average peak flow (30 c.s.m.) of the control watershed for the 1965-69 period, we would predict a flow of 37 c.s.m. for the logged watershed if it had remained unlogged and 46 c.s.m. if it were logged. The magnitude of this increase agrees roughly with those reported in the Alsea study in the Oregon Coast Ranges (see footnotes 2 and 3) and with Hewlett and Helvey's results from clear felling without logging in the southern Appalachians.

PEAKS FROM FIRST FALL STORMS INCREASED

Particularly significant are those streamflow peaks that are circled on figure 3. These resulted from the first large storms of the rainy season following the characteristically long, dry summers. We find that these streamflow peaks are from 40 to over 200 percent higher than we would have predicted from the prelogging relationship. Since similar size peaks measured later in the winter season (uncircled dots) show less deviation from predicted flows, it appears that at least part of the explanation could be related to antecedent moisture condition.

In another study nearby, at the end of the dry summer we have measured over 6 inches more water stored in the soil in logged areas than in adjacent timbered areas. Decreased evapotranspiration from the clearcut area results in less moisture storage capacity. This, in turn, results in greater streamflow from the clearcut during the first fall storms. In forested areas, more of this precipitation can be stored in the drier soils. To some lesser degree, this difference in soils can influence peak flows during other periods of the year, especially following extended periods of no precipitation and during early spring when transpiration is again more active. In midwinter, after soils are thoroughly and approximately equally wet, there appears to be little difference in peak flows of major storms between logged and unlogged areas.

ANTECEDENT PRECIPITATION INFLUENCES PEAK STREAMFLOW

Stepwise regressions relating peaks to antecedent precipitation were calculated for both watersheds for the period before logging (1957-62) and for the period after logging was essentially completed (1965-69).

Before logging on the logged watershed, precipitation the day of the peak flow was by far the most influential factor, accounting for 59 percent of the variation in size of peak, i.e., $r^2 = .59$; the 30-day antecedent precipitation accounted for another 8 percent; the day number of the streamflow peak and the 6-hour intensity, another 2 percent each. Total variation explained by the four factors was 71 percent.

After logging, precipitation on the day of peak streamflow was again the most influential factor related to peak

flow, accounting for 56 percent of the variation; 6-hour intensity accounted for another 6 percent; 30-day antecedent precipitation, an additional 4 percent; and day number of the streamflow peak, 2 percent. Total variation accounted for was 68 percent. The 30-day antecedent precipitation factor as an indicator of soil wetness might well be less variable after logging, as we have indicated that soils in clearcut areas tend to dry out less than those under a complete forest cover. Similarly, after logging, we might expect streamflow to be more responsive to 6-hour intensity because more precipitation reaches the soil surface directly without first being intercepted by tree crowns.

30-Day Antecedent Precipitation

Since the presence or absence of a forest cover could influence soil wetness through evapotranspiration processes but have little or no influence on either total precipitation the day of the storm or 6-hour precipitation intensity, we next examined the 30-day antecedent precipitation (an indicator of soil wetness) in relation to peak flow for the periods before and after logging for both the logged and unlogged watersheds (fig. 4).

For the unlogged watershed, the regressions of peak flow to 30-day precipitation for both the period before (line 1) and the period after (line 3) logging

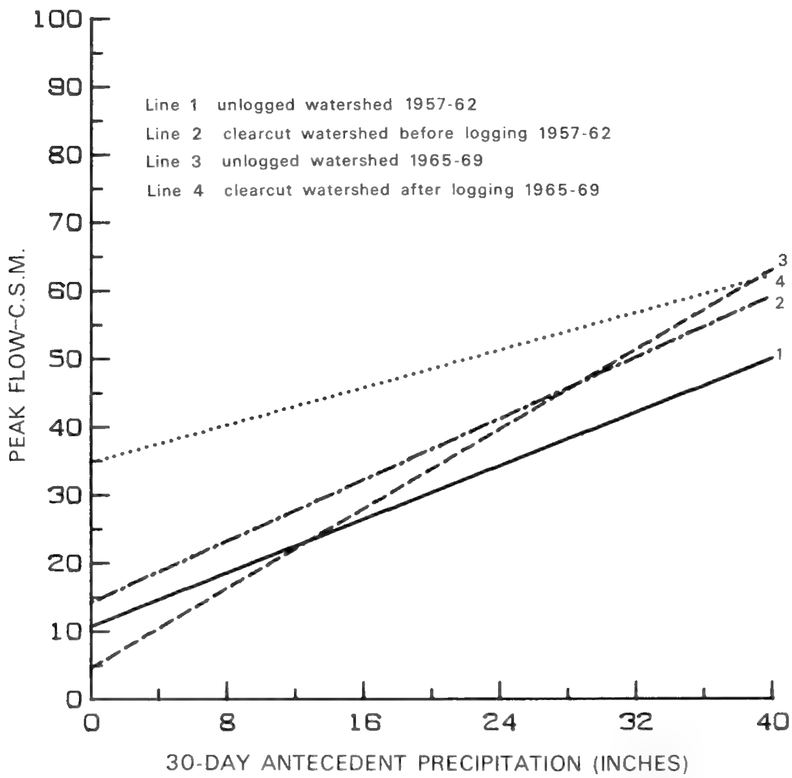

Figure 4.--*Influence of 30-day antecedent precipitation on peak flows for logged and unlogged watersheds.*

were highly significant. In a covariance analysis, slope of the regressions and the adjusted mean were nonsignificant (lines 1 and 3), indicating no difference between the two periods. We would expect this, since there was no change in cover on this watershed throughout the entire study.

For the logged watershed, the relationship shown in figure 4 was significant before logging (line 2) but nonsignificant after logging (line 4). As for the unlogged watershed, the slopes of the regressions were not significantly different, but the adjusted means were highly significantly different for the two periods (lines 2 and 4). This would suggest that logging increases the average peak flows, although any influence the 30-day antecedent precipitation has on streamflow is weak in the post-logging period. In figure 4, note that there appears to be a convergence of the before and after logging curves (lines 2 and 4) for the clearcut watershed at high 30-day precipitation totals. This is even more pronounced for the unlogged and clearcut watersheds for the 1965-69 period (lines 3 and 4). Data from our brief period of record show 30-day antecedent precipitation exceeded 37 inches. At this point, there is very little difference between the regressions, suggesting that logging may have relatively little influence on peak streamflow under excessively wet conditions.

The influence of the 30-day antecedent precipitation is illustrated in another form in figure 5, which shows how measured

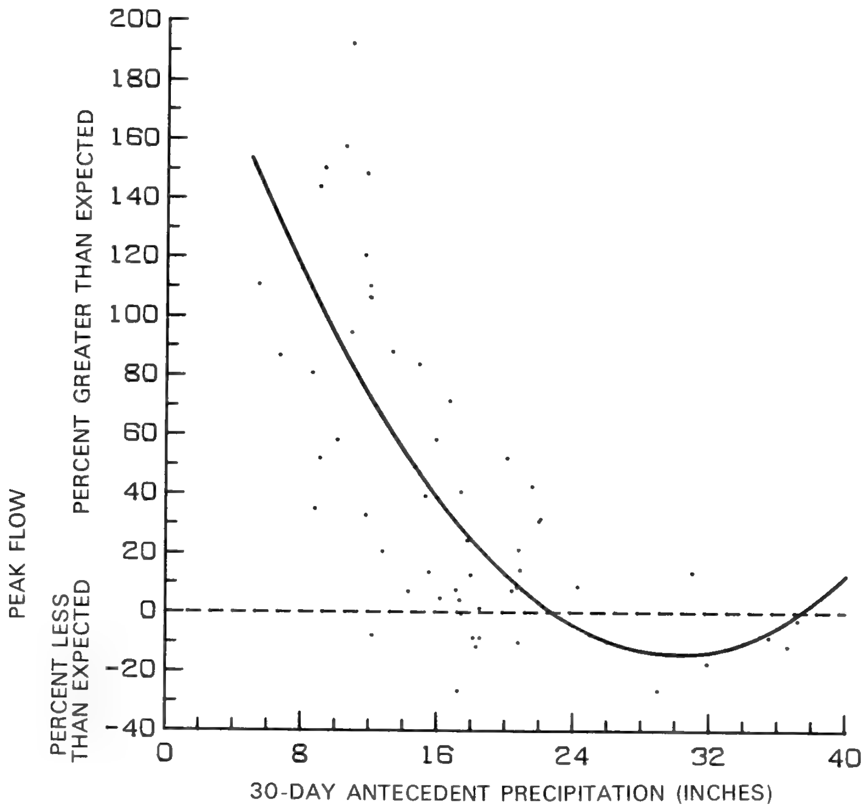

Figure 5.--*Measured peak streamflow as a percent of predicted peak at various degrees of wetness as expressed by 30-day antecedent precipitation.*

peak streamflow in the logged watershed varied as a percent of the predicted peaks at various degrees of wetness, as measured by 30-day antecedent precipitation. Peak flow from logged and unlogged watersheds are essentially the same at high antecedent precipitation. There is no reason to expect that logging would decrease peak streamflow, although the curve shows this. This figure illustrates the high degree of scatter associated with attempting to explain a complex relationship by only one factor. The one factor of wetness explains about 51 percent of the variation in peak streamflow ($r^2 = .51$).

ABOVE AVERAGE STREAMFLOW PEAKS LITTLE CHANGED

The maximum storm of record is the highest peak on figure 3. Measured flow was actually less than we would have predicted from prelogging relationships, although this is probably due to variation in timing of snowmelt. All but four of the 15 peak flows greater than the postlogging mean are within 8 c.s.m. of the level we would have predicted from the before-logging relationship--some larger, some smaller. Two of the exceptions were the first fall storms in 1965 and 1969 and could be largely attributed to greater runoff from wetter soils in the clearcut. The other two exceptions involved rain-on-snow events.

Although the evidence is incomplete, it seems reasonable from this and other studies to imply that although clearcut logging of an entire watershed with deep porous soils increases peak streamflow under relatively dry conditions, even this extreme change in cover has little influence on peaks when excessively wet conditions occur.

INCREASED PEAKS DO NOT REACH EXCESSIVE LEVELS

Recognizing that some peak flows are increased as a result of clearcut logging, we are faced with the question whether the increased peaks reach excessive levels.

In 17 years of study of the logged watershed, I have recorded 12 peak flows greater than 100 c.s.m. (Peak streamflow of 100 c.s.m. is sufficiently high to be important to downstream flooding.)

	Peak flow (c.s.m.)
1953	111 Estimated
1954	113
1957	138
1958	139
1962	115
1964	105 watershed 55 percent logged
1965	112 watershed 70 percent logged
	165
	138
1966	109 watershed 90 percent logged
1969	117 watershed 100 percent logged and burned
1969	108

Of the postlogging peak flows that were higher than predicted (fig. 3), three were greater than 100 c.s.m. The largest, 117 c.s.m., was considerably less than several prelogging peaks. Two other peaks associated with the major regional floods of 1964-65 were much higher, but were less than predicted. Only one is shown on figure 3, as records for the other were estimated for the unlogged watershed. One other peak of 108 c.s.m. was approximately the height predicted.

Although some postlogging peaks were increased to relatively high levels, none of those that were larger than predicted have exceeded previous high

streamflow peaks. Major floods typically occur from mid-November on. Two of the postlogging peaks over 100 c.s.m. occurred early in the wet season at a time when major floods are unlikely. Later major storms that occur under thoroughly wet soil conditions would be expected to produce streamflow peaks little changed by logging.

PATCHCUT LOGGING HAS MINOR INFLUENCE ON STREAMFLOW PEAKS

Under current patchcutting practices, only about 1 to 2 percent of large drainages are cut at any one time. On smaller drainages of several hundred acres, approximately one-quarter of the area might normally be clearcut within a few years. In our study, an adjacent 250-acre watershed with 1.65 miles of logging road (8 percent of drainage disturbed) and 25-percent clearcut showed minor increases similar to the clearcut and logged watersheds we have been discussing. The regression relationships of the unlogged and patchcut logged watersheds were calculated for the period before logging (fig. 6, line 1), after road construction (line 2), and after roads, logging, and burning (three clearcut units, 25 percent of area) (line 3). All these regressions were highly significant.

Comparing the period after road construction (fig. 6, line 2) with the period when both watersheds were

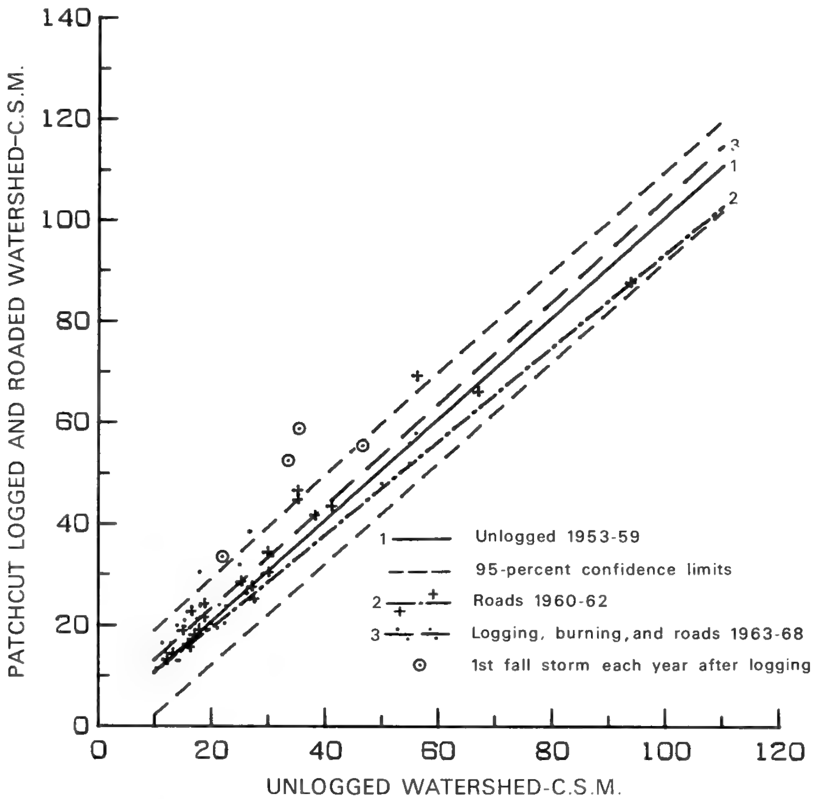

Figure 6.--*Peak streamflow relations of patchcut and unlogged watersheds on the H. J. Andrews Experimental Forest before logging, after road construction, and after logging and roads. Data points for unlogged relationship not shown.*

unlogged (line 1), I found that the slopes of the lines were highly significantly different. There appears to be no logical reason why the slopes should be different in the direction shown (lower peaks after roads).

Comparing the period after logging which includes road construction (fig. 6, line 3) with the before-logging period (line 1), I found a nonsignificant difference in slope but a highly significant difference in adjusted means--27.5 c.s.m. before, 30.3 c.s.m. after logging and roads. I see no evidence of a trend toward less change at high flows, most probably because no peak flows greater than 60 c.s.m. are included in the analysis. Unfortunately, records of the largest storms during the period were lost when the gaging station on the patchcut and roaded watershed was damaged by a debris avalanche during a 50- to 100-year storm (Fredriksen 1965).

Later records for 1969, 1970, and 1971 show no significant change from prelogging peak flows. By this time, 6 to 8 years after burning, the clearcut areas were covered by a regrowth of vegetation that gave crown coverage over almost 90 percent of the area, although about 23 percent of the soil surface was still classified as bare.

It seems safe to conclude from this that under the common patchcut form of clearcut logging, the harvesting of timber will result in appreciably increased peak runoff only under unusual circumstances. Two conditions that might cause increased runoff are (1) exceptionally large quantities of precipitation at the end of the dry season when there is a marked difference in soil wetness and (2) a rain-on-snow event in which large quantities of precipitation coincide with melt of a larger accumulation of snow in logged areas. Because of timing of precipitation and snowmelt, the latter situation is so highly variable that peaks from logged watersheds are sometimes higher, sometimes lower than would be expected if the area were uncut.

CONCLUSIONS

Peak streamflow from small watersheds in areas typified by the H. J. Andrews Experimental Forest is increased by logging when antecedent precipitation is low, i.e., when water storage capacity of soils is less in the logged area than under the forest. If we examine only the size of the average peak flows, we would conclude that logging increases peak streamflow. However, the highest peak flows for a given watershed are the result of wet mantle conditions and may be associated with rain-on-snow events. Under these conditions there are indications that the highest peak flows from logged watersheds are rarely greater than they would have been if no logging occurred. Statistical evidence is weak, but present indications point to the overriding influence of climatic pattern in determining major peak streamflow. More data are needed, but they are difficult to obtain because of the infrequency of major storm events coinciding with treatment of gaged watersheds. Even without additional data, it would appear that the design of structures to handle the water in small streams does not need an additional safety factor for increased peak runoff from logged areas to avoid water damage. However, modifications of capacity or design of drainage structures may be required to handle debris. In analysis of flood damage caused by the recordbreaking storms of 1964-65, Rothacher and Glazebrook (1968) found that most culverts were hydraulically adequate. Those that failed were plugged with debris.

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